Correlating differences in the playing properties of five student model clarinets with physical differences between them

ACOUSTICS 2012

Correlating differences in the playing properties of five student model clarinets with physical differences between them

P. M. Kowal, D. Sharp and S. Taherzadeh

Open University, DDEM, MCT Faculty, Open University, Walton Hall, MK7 6AA Milton Keynes, UK
paulina.kowal@open.ac.uk

This paper reports work that is part of a larger project concerned with correlating differences in the perceived playing characteristics of musical wind instruments with physical differences between them. Here we focus on five different student model clarinets. Some of the practical difficulties of (i) directly measuring the bore profiles of the clarinets and (ii) measuring their input impedances are discussed. Results are presented which show significant differences in bore profile between the five instruments, leading to clear differences in the frequencies and magnitudes of their resonance peaks. In addition, some initial thoughts regarding playing tests designed to establish clarinetists' perceptions of the instruments are considered.

1 Introduction

Physical differences, such as variations in geometry, between musical wind instruments of a given type generally lead to differences in their resonance properties and, consequently, in their playing characteristics. The work reported in this paper is part of a larger project concerned with attempting to correlate differences in the perceived playing characteristics of musical wind instruments with physical and acoustical differences between them.

This study focuses on five student model clarinets made by different manufacturers: a Boosey and Hawkes Regent instrument, a Buffet B12 instrument, a Corton instrument, a Jazzo instrument and a Yamaha 34IIS instrument (see Figure 1).

Figure 1: Five student model clarinets used in the study

In the next section, some of the challenges associated with directly measuring the internal geometries of clarinets are discussed and bore profiles of the five student model clarinets are presented and compared. Then, in Section 3, some practical issues associated with making input impedance measurements on clarinets are described. The advantages and disadvantages of two different capillary-based impedance measurement systems are considered and issues associated with each system are investigated. Input impedance curves for the five clarinets, with a variety of fingerings applied, are presented and compared. Differences between the impedance curves of the five instruments are related to variations in their bore profiles. Finally, in Section 4, some initial thoughts regarding playing tests designed to establish clarinetists' perceptions of the instruments are considered.

2 Bore profile measurements

For a musical wind instrument such as a trumpet, whose air column is contained within curved tubing that bends back on itself several times, the non-invasive technique of acoustic pulse reflectometry provides a useful means of measuring the bore profile [1]. However, for a straight bore wind instrument such as the clarinet, the most direct way of measuring the internal geometry is to use a set of high precision measurement discs with rod attachments.

For each of the five clarinets in turn, progressively smaller diameter measurement discs were sequentially inserted into (i) the assembled bell and bottom joint and (ii) the assembled upper joint and barrel, with the insertion depth noted each time. The diameters of the measurement discs used ranged from 55.0 mm down to 14.7 mm.

A problem was encountered when measuring the assembled upper joint and barrel; because two of the toneholes in the upper joint of the clarinet protrude into the main bore, it was not possible to measure regions upstream of these toneholes using the full discs. To overcome this issue, a small number of cut-down discs were made. To make each cut-down disc, two equal-sized circular segments were removed, at locations 180 degrees apart, from a newly-produced complete disc. It was possible to manoeuvre these cut-down discs past the protruding tone-holes, thus enabling regions upstream to be measured in the usual manner. Figure 2 shows the set of measurement discs and rods; the inset highlights one of the cut-down discs.

Figure 2: Set of measurement discs and rods; a cut-down disc is highlighted.

By combining (i) the bell/lower joint measurements and (ii) the upper joint/barrel measurements, full bore profiles for all five clarinets have been determined. The most significant differences between the profiles are observed over the region of the bell and the lower joint. These differences can be clearly seen in Figure 3, which shows a 250 mm section of the instrument bores, starting from the bell and progressing up into the lower joint.

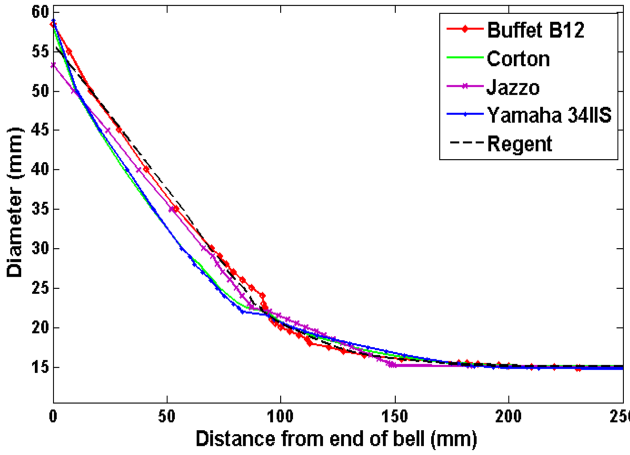

Figure 3: Bore profiles of five student model clarinets, starting from the bell and progressing into the lower joint.

Close inspection of Figure 3 reveals that the Yamaha 34IIS and Corton clarinets have remarkably similar bore profiles, with a smooth, flaring expansion that starts in the lower joint and continues on into the bell. The bore profiles of the Buffet B12 and B&H Regent clarinets are also quite alike over the lower joint. However, they then deviate from each other, with the bell of the Buffet B12 exhibiting a slight flare while the bell of the B&H Regent is more conical in shape. Meanwhile, the bore of the Jazzo clarinet is essentially made up of three parts; a cylindrical section over the majority of its length, a slowly expanding conical section starting 15cm from the end of the instrument, and a more rapidly expanding conical section over the final 8cm of the instrument.

Measuring the bore profiles of the instruments provides a great deal of information about their relative geometries. However, in order to obtain full physical maps of the instruments, it is planned to carry out detailed measurements of the positions, sizes and shapes of the toneholes, as well as the elevations of the keys/pads above the holes.

The internal geometry of a musical wind instrument essentially defines the resonance properties of the instrument. In the next section, input impedance measurements on the five clarinets are reported and differences between them are discussed in terms of the physical variations between the instruments.

3 Input impedance measurements

In the study of musical wind instruments, the measurement of input impedance as a function of frequency has proved particularly useful [2,3]. Impedance magnitude and phase curves provide information about both the strengths and frequencies of the instrument's air column resonances. In most playing situations, it is these air column resonances, rather than the reed or lip vibrations, that control the oscillation. Consequently, impedance curves can impart a great deal of information about the playing characteristics of an instrument.

The Acoustics Research Group at the Open University owns two different capillary-based systems for measuring input impedance; a set-up that has been designed and built in-house [4] and a commercially available BIAS system [5,6]. Each set of apparatus has advantages and disadvantages.

With the in-house measurement set-up, the microphone and capillary are located in the centre of a large diameter, flat metal plate. This arrangement offers a high degree of flexibility in terms of the range of instruments that can be easily mounted on the apparatus. The system provides very accurate measurements of complex input impedance but, in order to maintain a high signal-to-noise ratio, a complete measurement across the frequency range of interest can take up to 40 minutes. Thus, when measuring woodwind instruments, some form of clamping must be applied to the keys when investigating different fingering combinations.

In contrast, the BIAS system provides accurate impedance measurements in a matter of seconds, enabling different fingerings to be applied directly by a player. However, the BIAS system is designed specifically for the measurement of brass instruments; although it is possible to measure woodwind instruments using BIAS, this involves designing and building bespoke couplers.

To be able to directly relate input impedance measurements of the five student model clarinets to players' perceptions of the instruments, it is necessary in each case to measure the complete instrument including the mouthpiece. This has been successfully achieved using an impedance spectrometer [7] but presents challenges for both sets of capillary-based measurement apparatus reported here. The following sections present input impedance measurements made on the five student model clarinets with various fingerings across the playing range applied. The results illustrate some of the issues associated with the two measurement systems, as well as enabling the resonance characteristics of the clarinets to be compared.

3.1 In-house measurement system

A clarinet mouthpiece has a curved face with an approximately rectangular window cut into it (under normal playing conditions, this window is covered by the flat surface of the reed). In order to make an input impedance measurement on a complete clarinet, the rectangular window in the mouthpiece must be positioned over the capillary and microphone of the measurement apparatus.

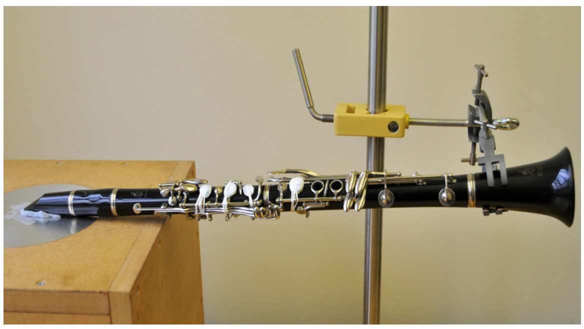

Figure 4: Buffet B12 clarinet mounted on in-house capillary-based impedance measurement system.

Figure 4 shows the Buffet B12 clarinet mounted on the OU Acoustics Research Group in-house capillary-based impedance measurement system. In order that the rectangular window in the mouthpiece covers the capillary and microphone fully, the clarinet is positioned approximately horizontally on the apparatus. A ring of putty is applied around the mouthpiece to create an air-tight seal between it and the metal plate.

To test this measurement configuration, a series of input impedance measurements was made on the Buffet B12 clarinet. The fingering for the note Bb3 was applied by sealing the necessary holes with putty and using PTFE tape to bind the required keys down; one of the authors (PK) played the instrument to verify that the note sounded correctly. The clarinet was then mounted on the apparatus as described above and a measurement was made. When the measurement was finished, the clarinet was removed from the apparatus. The process was then repeated three further times.

Figure 5 shows the resulting four impedance curves for the clarinet with Bb3 fingering applied. The variations between the curves clearly indicate a lack of reproducibility arising as a result of the measurement configuration. Two possible causes of this lack of consistency were identified; (i) loosening of the PTFE tape during the measurement period, resulting in small changes in the pressures applied to the keys between measurements, and (ii) sensitivity to small variations in the positioning of the clarinet between measurements, accentuated by difficulty of coupling the curved mouthpiece surface to the flat plate.

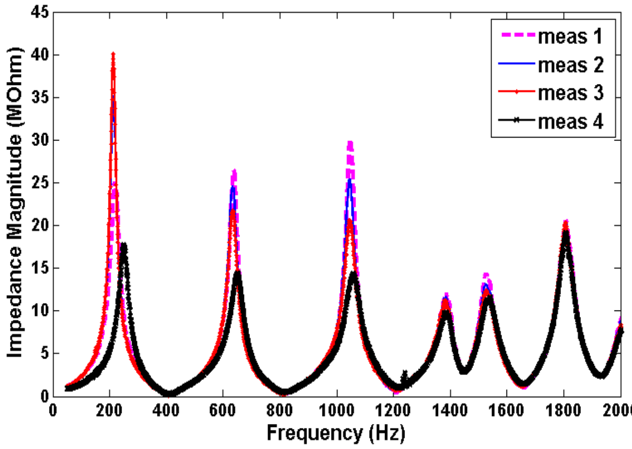

Figure 5: Impedance magnitude curves for complete Buffet B12 clarinet; Bb3 fingering applied using putty/PTFE tape.

To investigate the first possibility, the fingering for the note Bb3 was applied using a combination of putty and PTFE tape as before. The clarinet mouthpiece was then removed and the main body of the instrument was mounted vertically on the apparatus. This ensured a more reliable coupling between the instrument and the metal plate. Input impedance measurements were made at intervals throughout the day. The results are shown in Figure 6. It is clear that, despite the more reliable coupling between the instrument and the apparatus, differences are still apparent between the curves. Close inspection reveals that the magnitudes of the peaks gradually lessen as time progresses and their frequencies increase slightly. This behaviour is entirely consistent with the hypothesis of the PTFE tape slowly loosening over the measurement period.

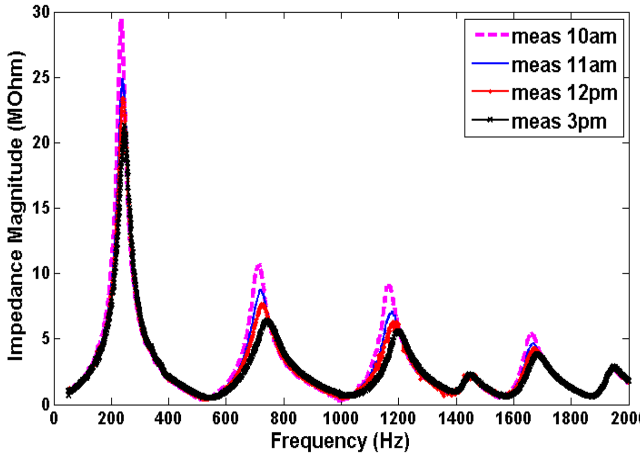

Figure 6: Impedance magnitude curves for Buffet B12 clarinet without mouthpiece; Bb3 fingering applied using putty/PTFE tape.

A further experiment was carried out using a new clamping arrangement to apply the Bb3 fingering. Instead of using PTFE tape and putty, a set of small clamps with rubber pads to imitate human fingers was applied to the necessary keys/holes. As before, with the clarinet mouthpiece removed, the main body of the instrument was mounted on the apparatus and impedance measurements were made at regular intervals. Figure 7 shows the resulting impedance curves. By comparing with Figure 6, it is immediately apparent that the new clamping arrangement has significantly improved the repeatability of the measurements.

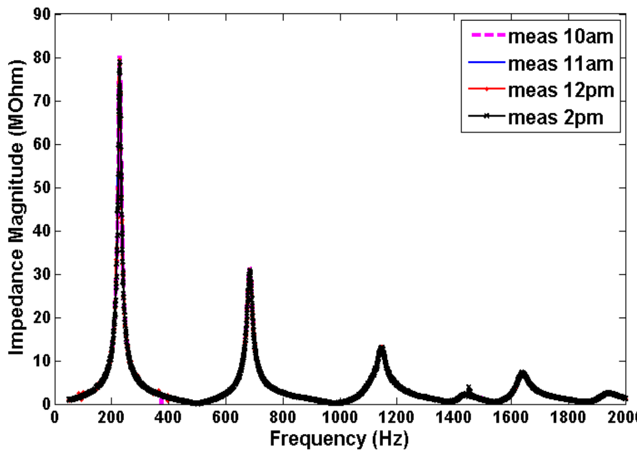

Figure 7: Impedance magnitude curves for Buffet B12 clarinet without mouthpiece; Bb3 fingering applied using small clamps.

The second possible cause of the inconsistency observed in Figure 5 was sensitivity of the measurements to small variations in the positioning of the clarinet on the apparatus. To investigate this, the clarinet mouthpiece was reattached and the complete instrument was again mounted on the apparatus in the configuration shown in Figure 4. However, this time the new clamping arrangement (instead of the PTFE tape and putty) was used to apply the Bb3 fingering. As before, a measurement was made and, when the measurement was finished, the clarinet was removed from the apparatus. The process was repeated three further times. The results are shown in Figure 8. It is clear that, despite the improved clamping arrangement used to apply the fingering, variations are still present between the curves. This inconsistency can therefore be entirely attributed to the difficulty of coupling the curved mouthpiece surface to the flat plate in a reproducible manner.

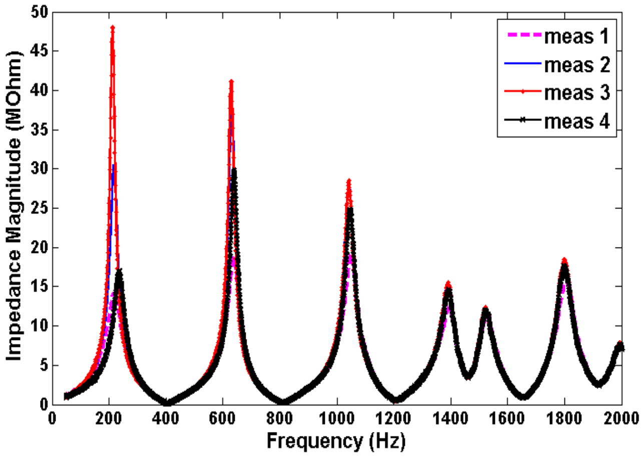

Figure 8: Impedance magnitude curves for complete Buffet B12 clarinet; Bb3 fingering applied using small clamps.

To address this issue, a coupler is currently being constructed which comprises a clarinet mouthpiece cast in a resin block. The block will provide a flat contact surface and should ensure that the clarinet can be mounted on the apparatus more reliably.

3.2 BIAS measurement system

BIAS is a commercially available input impedance measurement system. It is primarily designed for the testing of brass instruments, and its clamping system has been optimised to ease the attachment of such instruments. However, bespoke couplers can be produced to enable measurements on woodwind instruments. In [8], a coupler is described which allows an oboe with staple to be attached to the BIAS system.

Coupling a complete clarinet (including mouthpiece) to the BIAS system presents a greater challenge. The threaded metal sleeve and bayonet locking ring that comprise the BIAS clamping system do not enable instruments to be mounted transversely. Consequently, a new clamping system is currently being designed to (i) replace the metal sleeve and bayonet locking ring arrangement and (ii) allow a clarinet mouthpiece to be firmly mounted transversely on the BIAS system.

To enable measurements to be made on the five student model clarinets while the new clamping system is being developed, a bespoke coupler has been produced that enables the main body of a clarinet to be mounted on the BIAS system vertically (see Figures 9 and 10). The coupler is inserted into the barrel of the clarinet and is then clamped to the BIAS head in the usual way. The coupler therefore takes the place of the clarinet mouthpiece. Indeed, an 11.9 cm^3 cylindrical volume within the coupler separates the BIAS head from the main body of the instrument. This volume is equivalent to that contained within a clarinet mouthpiece (determined by filling a mouthpiece with water and transferring the water to a measuring cylinder).

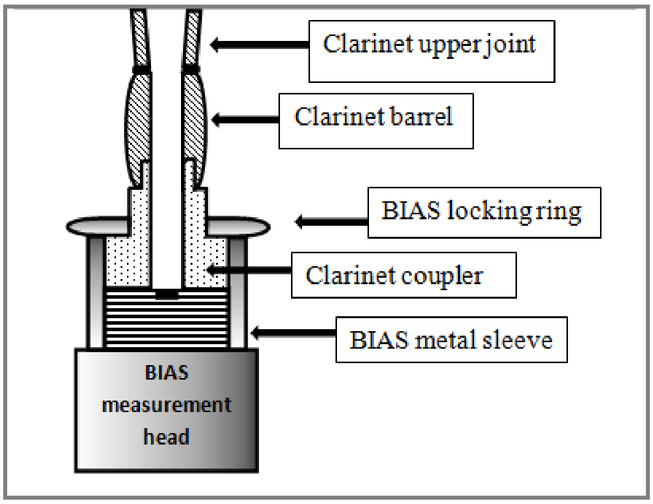

Figure 9: Schematic diagram of BIAS measurement head coupled to clarinet

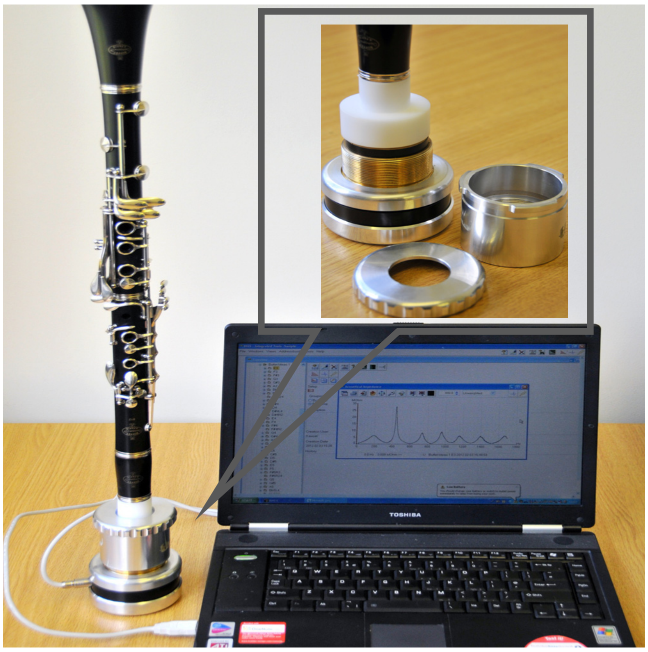

Figure 10: Clarinet mounted on BIAS measuring system via bespoke coupler

Using the BIAS system with the bespoke coupler, input impedance measurements were made on the five student model clarinets for all note fingerings from E3 to G6 in semitone intervals. Some example results are presented here.

Figure 11 shows the measured impedance curves for the five clarinets when fingering E3 was applied. In this fingering configuration, all the toneholes are covered so the impedance of the instrument is essentially defined by its bore profile. It is maybe not surprising to see, therefore, that the impedance curves for the Yamaha 34IIS and Corton clarinets are in close agreement. In particular, the insets show that, for the first two peaks in their curves, the amplitudes agree to within 1 MΩ and the frequencies agree to within 1 Hz.

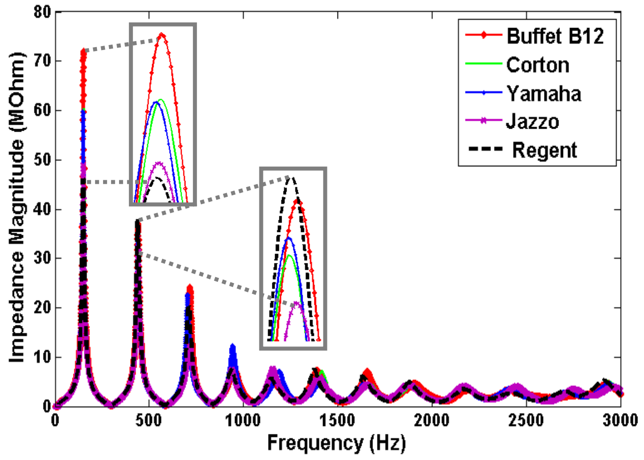

Figure 11: Impedance magnitude curves for five student model clarinets with E3 fingering applied.

Much larger differences can be seen between the impedance curves for the other clarinets. Although the frequencies of the first peaks still agree to within 1 Hz, the amplitudes range from 46 MΩ in the case of the B&H Regent, up to 72 MΩ in the case of the Buffet B12. Meanwhile, the frequencies of the second peaks vary by 3.5 Hz and their amplitudes range from 32 MΩ in the case of the Jazzo, up to 38 MΩ in the case of the B&H Regent. These variations are a direct result of the differences observed in the bore profiles of the instruments and will result in differences in the playing properties of the instruments (intonation, playabilities of notes, timbre etc).

Figure 12 shows the impedance curves for the five clarinets when fingering G4 was applied. With this fingering configuration, no keys are pressed down and all the toneholes are left open. Consequently, the positions and geometries of the toneholes, together with the elevations of the unpressed keys, now also play a significant role in defining the instrument's impedance. Examination of the impedance curves reveals a wider variation between them than was observed in Figure 11. In particular, now that the bore profiles are not the only defining factor, the impedances curves for the Yamaha 34IIs and Corton clarinets are no longer in such good agreement. The amplitudes of the first peaks differ by 3 MΩ while their frequencies vary by 4.5 Hz. The amplitudes of the second peaks are more closely matched, agreeing to within 0.5 MΩ, but their frequencies differ by 8 Hz.

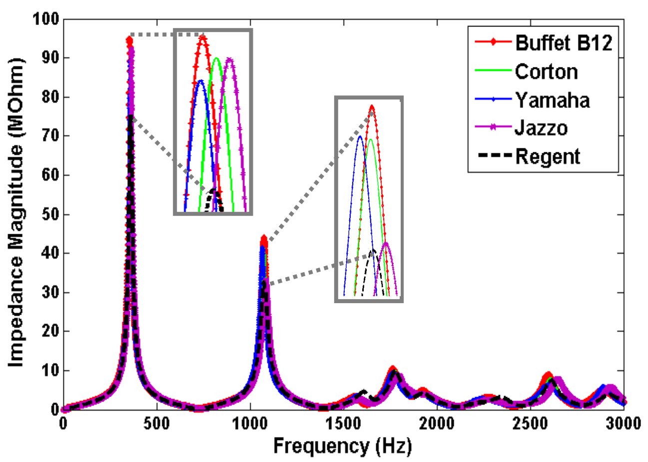

Figure 12: Impedance magnitude curves for five student model clarinets with G4 fingering applied.

Looking at the impedance curves for the other clarinets, the amplitudes of the first peaks range from 75 MΩ in the case of the B&H Regent, up to 95 MΩ in the case of the Buffet B12 (following a similar trend to that seen in Figure 11 for the E3 fingering). The frequencies of the first peaks vary by 8 Hz. Meanwhile, the amplitudes of the second peaks range from 33 MΩ in the case of the B&H Regent, up to 44 MΩ in the case of the Buffet B12. The frequencies of the second peaks vary by 20 Hz.

Figure 13 shows the impedance curves for the five clarinets when fingering E5 was applied. This note falls in the second register of the instrument. The impedance curves in this higher register will be strongly influenced by the exact locations and sizes of the relevant register hole. Again, examination of the figure reveals significant variations between the impedance curves of the clarinets, both in terms of the amplitudes and frequencies of the peaks.

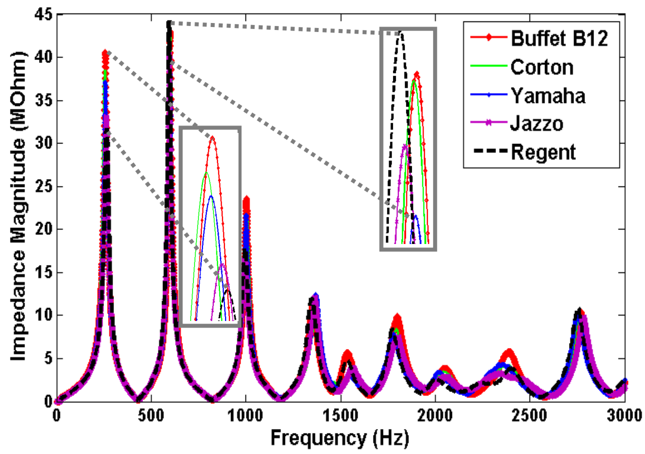

Figure 13: Impedance magnitude curves for five student model clarinets with E5 fingering applied.

Once the positions and geometries of the toneholes in the five clarinets have been measured, providing full physical maps for the instruments, it is intended to undertake a further detailed analysis of the input impedance curves and attempt to relate differences between them to physical variations between the instruments.

4 Concluding remarks

Bore profile and input impedance measurements have been made on five student model clarinets produced by different manufacturers. Differences between the internal profiles of the instruments have been found and have been shown to lead to variations in the resonance properties of the instruments.

The ultimate aim of this work is to correlate differences in the perceived playing properties of the clarinets with physical and acoustical differences between them. To this end, the next stage of the study will involve carrying out a series of playing tests, involving musicians of various standards, from amateur to professional players. The tests will involve participants playing notes on the five clarinets over the whole range of the instrument and then rating properties such as intonation, responsiveness, quality of sound and playability. The results from the playing tests will be statistically analysed and an attempt will be made to correlate the findings with the physical and acoustical measurements made on the instruments.

5 References

[1] D.B. Sharp, J.M. Buick, "Measurement of musical wind instruments using acoustic pulse reflectometry", *Proc. of the Institute of Acoustics* 21(3), 191-198 (1999)

[2] J. Backus, "Input impedance curves for the reed woodwind instruments", *J. Acoust. Soc. Am.* 56(4), 1266-1279 (1974)

[3] J. Backus, "Input impedance curves for the brass instruments", *J. Acoust. Soc. Am.* 60(2), 470-480 (1976)

[4] D.B. Sharp, A. Mamou-Mani, M. van Walstijn, "A single microphone capillary-based system for measuring the complex input impedance of musical wind instruments", *Acta Acustica united with Acustica* 97(5), 819-829 (2011)

[5] G. Widholm, H. Pichler, T. Ossmann, "BIAS: A computer-aided test system for brass wind instruments", *Audio Engineering Society Pre-print*, 2834 (1989)

[6] G. Widholm, "Brass wind instrument quality measured and evaluated by a new computer system", *Proc. of the 15th Int. Congress on Acoustics, Trondheim,* Vol. 3, 517-520 (1995)

[7] P. Dickens, R. France, J. Smith, J. Wolfe, "Clarinet acoustics: Compendium of impedance and sound spectra", *Acoustics Australia* 35(1), 17-24 (2007)

[8] A. Mamou-Mani, D.B. Sharp, T. Meurisse, W. Ring, "Investigating the consistency of woodwind instrument manufacturing by comparing five nominally identical oboes", *J. Acoust. Soc. Am.* 131(1), 728-736 (2012)